ALTERATIONS IN CANOLA RESIDUE COMPOSITION DURING DECOMPOSITION*

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Summary—Surface-placed crop residues protect agricultural soils from the destructive forces of wind and water erosion. Knowledge of changes in residue composition during decomposition of differentially placed crop residue is important in understanding the potential effects of conservation tillage systems on soil quality properties, including C and N conservation and soil tilth. Compositional changes in C and N components of buried and surface-placed canola (*Brassica campestris* L.) residue were determined during decomposition in a cold, semiarid climate. Decomposition during the period of 23 March to 24 August 1995 was 57 and 30% for total mass, 53 and 25% for acid-detergent fiber, 46 and 46% for total N and 17 and 17% for lignin components when residue was buried and surface-placed, respectively. Of the 2.13 g N m^{-2} applied as canola residue, 0.79 g N m^{-2} was initially present as lignin-bound N and an additional 0.21 and 0.15 g N m^{-2} was sequestered as lignin-N when buried and surface-placed, respectively. *In situ* mineralization from total residue N was 87 and 82% of non-lignin-bound N in buried and surface-placement, respectively. Surface-placed canola residue had greater mass remaining and lower total and lignin N concentration than buried residue. These features of crop residues under conservation tillage systems are important for protecting soil from erosion and improving water infiltration and utilization by crops. Copyright © 1996 Elsevier Science Ltd

INTRODUCTION

Surface placement of crop residues with conservation tillage can improve soil physical, chemical, and biological properties compared with incorporation of residues with conventional tillage (Hatfield and Stewart, 1994). Soil organic matter increases with surface placement of crop residues compared with incorporation, especially in warmer climates (Doran, 1987), where decomposition of buried residues is faster than in colder climates (Carter and Rennie, 1982). Specific mechanisms that lead to increases in soil organic matter due to surface placement are not well understood. Less favorable conditions for decomposition or greater chemical resistance to decomposition are generally assumed. Whether surface-placed residues become more chemically resistant to decomposition needs to be investigated in order to better understand nutrient cycling under conservation tillage systems.

Canola (*Brassica campestris* L.) is becoming an increasingly important crop in cooler regions of the Canadian Prairies. Information about the decomposition of canola residue, as well as other crop residues in a cold semiarid climate, however, is scant.

This region-specific information is needed to validate and modify crop residue decomposition models (Stroo *et al.*, 1989).

Chemical alterations during decomposition may be different in buried and surface residues (Harper and Lynch, 1981). Nitrogen concentration (initially 34 mg N g^{-1}) of surface-placed hairy vetch (*Vicia villosa* Roth.) during decomposition (78%) in Kentucky stabilized to 24 mg N g^{-1} residue remaining at the end of 4 weeks in the field, while buried residues stabilized to 17 mg N g^{-1} residue remaining during decomposition (93%) (Varco *et al.*, 1993). Under laboratory conditions, a repeated 5-d drying–wetting cycle that simulated surface placement resulted in greater N concentration (24 vs 17 mg N g^{-1} residue remaining) from cowpea [*Vigna unguiculata* (L.) Walp.] compared with continuously moist conditions that simulated buried placement, while C loss was unaffected by placement (Franzluebbers *et al.*, 1994). Drying of plant material at temperatures > 50°C can result in production of additional lignin-like polymers (Goering and van Soest, 1970). Greater N concentration of hairy vetch and cowpea subjected to more intensive drying–wetting cycles suggests that additional lignin-like polymers may also be produced during decomposition in soil. Incorporation of mineralized or partially-mineralized N into these lignin-like

polymers may, therefore, render a portion of N in surface-placed residue less mineralizable. It is unclear whether residues with lower N and higher lignin concentrations, such as canola, undergo similar transformations during decomposition. Understanding the sequestration of N into more resistant compounds is important for determining potential changes in nutrient availability with adoption of conservation tillage systems.

Our objective was to determine the changes in composition of buried and surface-placed canola residue during decomposition in the cold semiarid climate of northern Alberta. We hypothesized that surface-placed residue would undergo more extreme drying–wetting and temperature fluctuations than buried residue. This might result in increased production of lignin-like polymers rendering partially mineralized N less available during decomposition.

MATERIALS AND METHODS

Canola was grown under rainfed conditions on a silt loam soil near Beaverlodge, Alberta (55° 11′ N, 119° 32′ W). Mature canola stems left standing in the field after seed harvest were collected on 8 February 1995. Plant material was air-dried, chopped to a length of 30 to 50 mm, and thoroughly mixed. Five g of plant material were placed into circular nylon mesh bags (0.9 mm openings, 135 mm diameter) to achieve a rate of 357 g residue m^{-2}, similar to local production. Residue bags were placed; (i) on the surface, and (ii) at a depth of 100 mm below the surface of an alluvial medium-coarse sand collected from the Wapiti river. Sand and residue bags were contained in poly-vinyl chloride cylinders (150 mm diameter, 200 mm high). Sand was packed to a density of 1.3 mg m^{-3} at 100 to 200 mm depth and to a density of 1.0 mg m^{-3} at 0 to 100 mm depth. Cylinders were placed 200 mm apart on the soil surface on 23 March 1995. The space between cylinders was filled with soil and the entire area was covered with ≈100 mm of snow to mimic surrounding conditions at the time of placement.

Two cylinders from each placement regime were removed at each of eight retrieval dates: 28 April, 9 May, 22 May, 6 June, 20 June, 13 July, 28 July and 24 August 1995. Residue bags were oven-dried (35°C, 72 h), adhering sand removed from residue by hand-rolling over a 0.25 mm screen, and the cleaned residue further oven-dried (35°C, 24 h). Residues were ground in a mill to <1 mm for further characterization. At each of the retrieval dates, water content was determined at 0 to 50 mm and 100 to 150 mm depths by oven-drying (35°C, 72 h) a portion of the sand.

Total residue N content was determined using an automated, modified indophenol blue method (Bundy and Meisinger, 1994) for NH4–N concen-

tration of a Kjeldahl digest (Gallaher *et al.*, 1976). Lignin, lignin-N, ash and acid-detergent fiber contents were determined with an acid-detergent fiber procedure (van Soest and Wine, 1968). Carbon compounds were characterized by solid-state ^{13}C cross polarization–magic angle spinning–nuclear magnetic resonance at 50.3 MHz on a Bruker CXP-200 spectrometer. To estimate the availability of remaining residues to microbial decomposition under standard conditions, CO_2–C production was determined from 100 mg of ground residue covered with 3 g purified sand (0.5–1 mm) and 0.3 ml water placed in a 25 ml plastic vial. The vial was placed into a 0.5-l canning jar along with additional vials containing 10 ml of 0.2 M NaOH to trap evolved CO_2 and water to maintain high humidity. Jars were kept at 25°C for 24 d with alkali traps replaced at 3 and 10 d. The amount of CO_2–C absorbed in the alkali was determined by titration with HCl (Anderson, 1982). Carbon mineralization under laboratory conditions was described with a two-pool exponential plus linear equation:

$$C_t = C_0(1 - e^{-kt}) + mt$$

where C_t is cumulative C mineralization at time t(d), C_0 is a rapidly mineralizable pool of substrates with an exponential rate of decomposition described by $k(d^{-1})$, and m is a linear rate of mineralization from more resistant substrates. At 24 d, inorganic N (NH_4–N + NO_2–N + NO_3–N) accumulation was determined by autoanalyzer techniques (Bundy and Meisinger, 1994) from a filtered extract obtained by shaking the residue with 10 ml of 2 M KCl for 1 h. Initial inorganic N of the residue was assumed to be negligible.

Differences in residue composition between buried and surface-placed canola during decomposition were determined with the general linear model procedure of SAS (SAS Institute Inc., 1990) using placement and retrieval date as sources of variation. Differences were considered significant at $P \leq 0.1$. One- and two-pool exponential equations were fitted to the data using non-linear regression on cumulative degree days (DD), in which DD is mean daily temperature (°$C_{>5}$). When deemed appropriate, linear regression was substituted for non-linear regression.

RESULTS AND DISCUSSION

Precipitation from 23 March to 24 August exceeded the long-term mean during this period by 29% (Table 1). However, DD and precipitation were slow to accumulate during the initial 47 days after placement (DAP) (Fig. 1(a)). Despite these environmental limitations to microbial activity, mass loss during the initial 47 DAP was 25% when residue was buried and 11% when residue was surface-placed (Fig. 2(a)). Leaching of the soluble

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Table 1. Environmental conditions during decomposition of canola residue. Residue was placed on 23 March 1995

Retrieval date	Days in period	Days with precipitation	Total precipitation	Mean low temperature	Mean high temperature	Degree days in period
			mm	°C	°C	°C$_{>5}$ d
28 April	36	12	29.5	−2.9	6.6	13
9 May	11	3	1.6	0.6	13.2	22
22 May	13	6	23.6	4.5	18.1	82
6 June	15	3	23.0	7.1	21.8	142
20 June	14	5	46.8	7.5	20.3	125
13 July	23	15	120.5	9.6	19.9	224
28 July	15	9	26.9	9.9	21.8	133
24 August	27	15	39.0	6.5	17.8	224
Total	154	68	310.9	4.7	16.2	965

component appeared to have predominated during this period. Microbial decomposition of the more available fraction was also important during this initial cold, dry period since buried residue under more favorable moisture conditions for microbial activity (Fig. 1(b)) lost 2.5 times more mass than surface-placed residue.

The rate of mass loss following disappearance of the easily-decomposable fraction was more than twice as great from buried residue as from surface-placed residue, as indicated by the exponential decay rates (Fig. 2(a)). Part of the lower decomposition rate with surface placement can be attributed to the lower soil water content during most of the incubation (Fig. 1(b)). The exponential rate of loss from the more resistant acid-detergent fiber pool was similar to the exponential rate of loss from the more resistant total mass under both placement

regimes (Fig. 2(a) and (b)). This result suggests that acid-detergent fiber components (cellulose, lignin and lignified N) were decomposing at a similar rate as soluble acid-detergent components (hemicellulose and fiber-bound protein) and soluble neutral-detergent components (lipids, sugars, organic acids, pectin, starch, non-protein N and soluble protein) (van Soest, 1982). The mathematically-described more resistant pool of residue accounted for 75% of total mass and 79% of acid-detergent fiber in buried residue, but 90% of total mass and 97% of acid-detergent fiber in surface-placed residue (Fig. 2(a) and (b)). At 965 DD, 57 and 30% of canola residue was lost when buried and surface-placed, respectively (Fig. 2(a)). The extent of decomposition of buried canola residue was similar to several wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.) varieties with low N concentration, where ≈50%
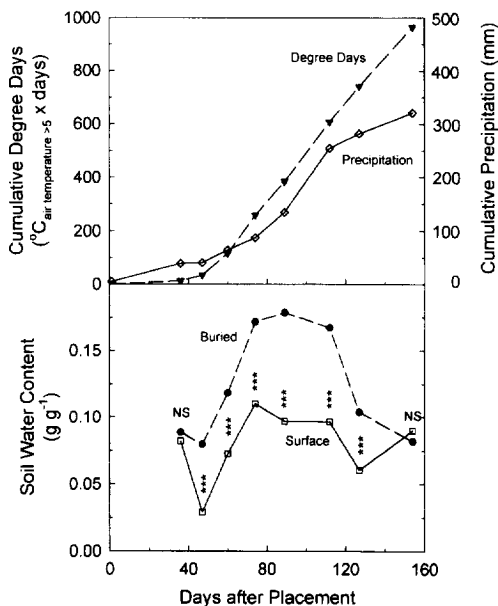

Fig. 1. (a) Cumulative degree days and precipitation; (b) soil water content; during decomposition of buried (100 mm depth) and surface canola residue. NS and *** indicate not significant ($P \leq 0.1$) and significance at $P \leq 0.001$, respectively. Soil water content was measured at 100–150 mm depth when buried and 0–50 mm depth when surfaced-placed.
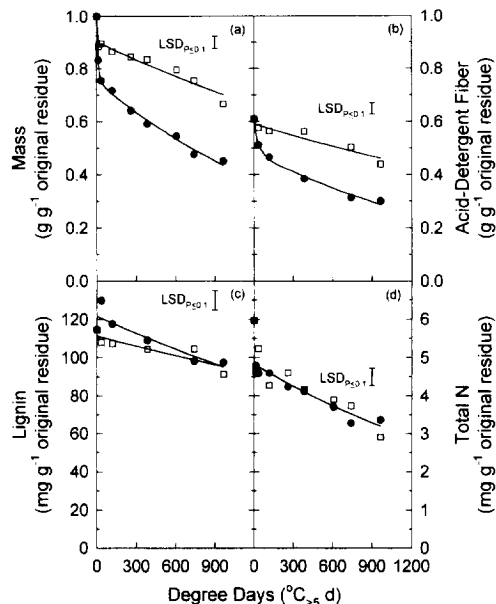
Fig. 2. (a) Mass remaining; (b), acid-detergent fiber remaining; (c) lignin remaining; (d) total N remaining; from buried (●) and surface-placed (□) canola residue as a function of degree days (DD) during decomposition in the field.

Table 2. Fraction of C compounds within aliphatic groups (0–50 ppm), C groups bound to O or N (50–110 ppm), aromatic and olefinic C groups (110–150 ppm), phenolic groups (150–170 ppm), and carboxyl groups (170–190 ppm) of canola residue buried at 100 mm (BUR) and placed on the soil surface (SFC) during 154 d of decomposition

	Chemical shift (ppm)									
	0–50		50–110		110–150		150–170		170–190	
Days after placement	BUR	SFC	BUR	SFC	BUR	SFC	BUR	SFC	BUR	SFC
0	0.07		0.76		0.09		0.04		0.05	
47	0.07	0.05	0.74	0.69	0.10	0.17	0.04	0.05	0.04	0.05
75	0.05	0.06	0.76	0.77	0.11	0.09	0.04	0.04	0.04	0.04
112	0.05	0.05	0.74	0.78	0.12	0.09	0.04	0.04	0.04	0.04
154	0.09	0.06	0.70	0.72	0.09	0.11	0.05	0.05	0.05	0.05
$LSD_{(P \leq 0.1)}$	0.03		0.09		0.05		0.01		0.02	

of mass was lost at 1000 DD (Douglas and Rickman, 1992).

No major changes in the relative quantities of C components due to placement or extent of decomposition were observed using ^{13}C NMR spectral analysis (Table 2). Integration of spectral peaks within the five categories selected should have provided a sensitive measurement of shifts in chemical composition during decomposition. Lack of clear differences between residue placement regimes using this technique indicates that structural C composition of decomposing canola residue was similar.

Carbon mineralization of buried residue remaining under laboratory conditions was 53 and 46% of initial residue mineralization at 89 and 154 DAP, respectively and of surface-placed residue remaining was 76 and 59% of initial residue mineralization at 89 and 154 DAP, respectively (Fig. 3). The lower C mineralization of buried residue remaining indicates that easily-decomposable fractions were lost faster than when surface-placed, corresponding directly to the more rapid initial mass loss observed in the field. Of the pool of rapidly mineralizable substrates (C_0), 80% was lost from buried residues in the field at 45 DD ($\approx$50 DAP), while surface-placed residues lost this amount at 965 DD (154 DAP) (Fig. 4(b)).

Carbon mineralization during the entire 24 d incubation in the laboratory from residues remaining became equivalent between placement regimes by $\approx$750 DD (Fig. 4(a)).

Lignin concentration of original canola residue was 115 mg g^{-1} residue. Loss of lignin was slow compared with mass and acid-detergent fiber loss (Fig. 2(c)). Five months after placement (965 DD), lignin concentration was 95 mg g^{-1} of original residue under both placement regimes. Lignin concentration of buried residue increased by 13% at 36 DAP, while that of surface-placed residue never increased above the original level. During the first 20 d of decomposition of ryegrass (*Lolium perenne* L.) under laboratory conditions, up to 5% increase in lignin concentration was observed (Horwath and Elliott, 1996). Lignin-like polymers, with sequestration of N, can be produced during heating of plant material in the presence of amino acids and water through the Maillard reaction (van Soest, 1982). Maillard reaction products doubled with an increase in drying temperature from 20 to 80°C. Higher temperatures were expected with surface placement, however a net increase in lignification occurred only with buried residue. Further research is needed to understand the extent of Maillard-like processes during residue decomposition.
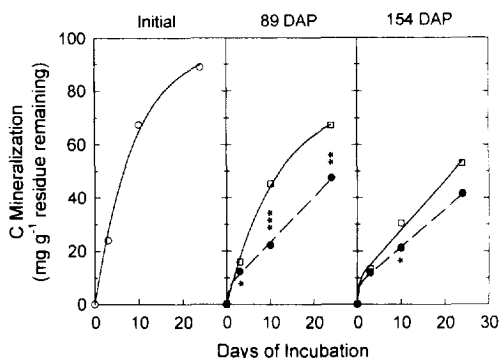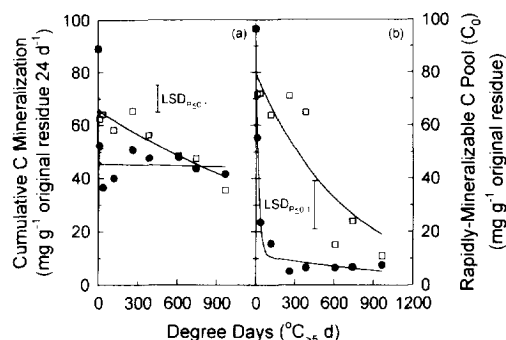

Fig. 3. Cumulative C mineralization during 24 d of incubation at 25°C from initial canola residue (O) and from residue remaining when buried at 100-mm depth (•) and placed on the soil surface (□) at 89 and 154 days after placement (DAP) in the field. *, ** and *** indicate significance at $P \leq 0.1$, $P \leq 0.01$ and $P \leq 0.001$, respectively.

Fig. 4. Carbon mineralization from buried (•) and surface-placed (□) canola residue incubated at 25°C for 24 d (a) and the size of the rapidly-mineralizable C pool (C_0) remaining from the 2-pool model (b): $[C_t = C_0(1 - e^{(-kt)}) + mt]$ as a function of degree days (DD) during decomposition in the field.

Loss of total residue N was similar for buried and surface-placed canola (Fig. 2(d)). The initial loss, calculated using the fitted exponential function, was 18% of total residue N. This result suggests that, even though N concentration of canola residue was low (6 mg N g^{-1}), a portion of N was rapidly susceptible to leaching or decomposition. The exponential rate of loss from the more resistant fraction of total residue N was only 0.75 as rapid as the more resistant fraction of mass when buried, but 1.6-fold more rapid as the more resistant fraction of mass when surface-placed (Fig. 2(a) and (d)). This resulted in an increase in N concentration of residue remaining when buried and a decrease in N concentration when surface-placed (Fig. 5(c)).

The initially low N concentration of canola residue resulted in insignificant and inconsistent amounts of mineralized N from residue remaining under laboratory conditions (data not shown). Mineralization of N averaged 0.3 and 0.5 mg N g^{-1} residue N remaining 24 d^{-1} for buried and surface-placed residue, respectively. An equation developed from different residue types and qualities using initial N and lignin concentrations (Vigil and Kissel, 1991), predicted net immobilization of 8–21 mg g^{-1} 11 wk^{-1}, due to the low total residue N and moderately high lignin contents.

Canola residue N content was equivalent to 2.13 g N m^{-2} initially and decreased to 1.18 g N m^{-2} under both placement regimes at the end of the
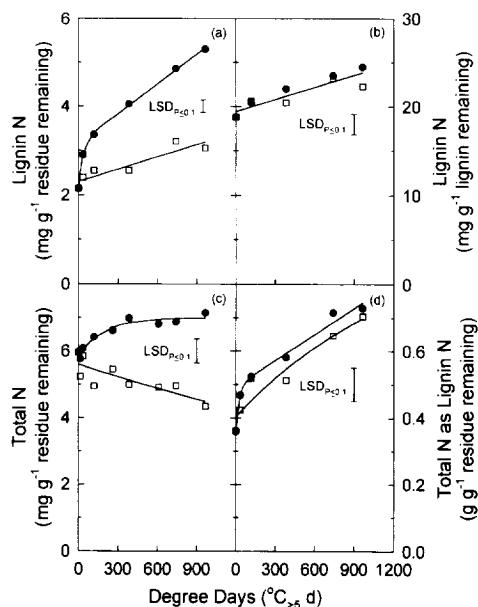

Fig. 5. (a) Lignin-N concentration of residue remaining; (b) N concentration of remaining lignin; (c) total N concentration of residue remaining; (d) fraction of total residue N remaining as lignin-N; from buried (●) and surface-placed (□) canola residue as a function of degree days (DD) during decomposition in the field.

field incubation (965 DD), resulting in in situ mineralization of 0.95 g N m^{-2}. The quantity of canola residue N mineralized was within the range of N mineralized from wheat (0.23 ± 0.03 g N m^{-2}) and sorghum (2.00 ± 1.01 g N m^{-2}) residues in Kansas (Wagger et al., 1985).

Contrary to our original hypothesis, additional N sequestered into the original quantity of lignin was greater when buried (11%, 0.23 mg N) than when surface-placed (2%, 0.05 mg N) (data not shown). Initial N concentration of lignin from canola residue was equivalent to the average N concentration of 19 mg g^{-1} from more than 40 forage and feces analyzed (van Soest, 1982), but increased under both placement regimes to 24 mg g^{-1} at 965 DD (Fig. 5(b)). Lignin-N of ryegrass increased 12–16% after 45 d of incubation under standard laboratory conditions (Horwath and Elliott, 1996).

Since the rate of mass loss was greater than the rate of lignin loss, in addition to N sequestration into the lignin fraction, the concentration of lignin-N increased from 2.2 mg N g^{-1} residue initially to 5.3 and 3.1 mg lignin-N g^{-1} residue remaining at 965 DD when buried and surface-placed, respectively (Fig. 5(a)). Reincorporation of mineralized N into lignin-like polymers likely contributed to the 19% increase in total N concentration of buried residue remaining at 965 DD compared with initial residue N concentration (Fig. 5(c)). Total N concentration of residue remaining when surface-placed was 18% lower at 965 DD than initial residue N concentration. As a fraction of total residue N remaining, lignin-N increased more initially (0 to 47 DAP) when buried than when surface-placed, but increased at a similar rate thereafter (Fig. 5(d)). The fraction of total residue N as lignin-N was 0.36 initially and increased to 0.78 at 965 DD when buried and 0.71 when surface-placed. Averaged across retrieval dates, the fraction of total residue N as lignin-N was 0.04 ± 0.03 greater ($P \leq 0.01$) when buried than when surface-placed.

Greater mass loss from canola residues when buried compared with surface-placement in the field is consistent with results from other crop residues. Decomposition of wheat buried at 120 mm depth after 1 year in Montana was 59% at one location (480 mm precipitation, 6°C) and 79% at another location (295 mm precipitation, 8°C), but decomposition was only 14 and 17%, respectively, when placed on the soil surface (Brown and Dickey, 1970). Mass loss of oat (Avena sativa L.) buried at 100-mm depth in nylon mesh bags after 1 year in England was 77%, but only 62% when placed on the soil surface (Harper and Lynch, 1981). Decomposition of crimson clover (Trifolium incarnatum L.) during 16 weeks of the summer (392 mm precipitation, 24°C) in Georgia was 71% when buried at 200-mm depth and 67% when placed on the soil surface (Wilson and Hargrove, 1986). In

Missouri, mass loss of corn (*Zea mays* L.), soybean [*Glycine max* (L.) Merr.], wheat, sorghum [*Sorghum bicolor* (L.) Moench] and cotton (*Gossypium hirsutum* L.) after 1 year (855 mm precipitation, 10°C) was 76 ± 4% when buried at 150-mm depth and 58 ± 13% when placed on the soil surface (Ghidey and Alberts, 1993). Residues with greater initial N concentration generally decomposed to a greater extent, but other crop-specific compositional factors may have been important. Initial lignin and N concentrations are crop-specific variables that have been used to predict net N mineralization from crop residues (Vigil and Kissel, 1991).

Our finding of greater N concentration of remaining canola residue when buried than when surface-placed agrees with several previously published findings, in which N concentration of buried residue remaining was greater than surface-placed wheat (Brown and Dickey, 1970; Douglas *et al.*, 1980) and crimson clover (Wilson and Hargrove, 1986). However, other studies have found that buried residues had lower N concentration remaining than surface-placed wheat (Holland and Coleman, 1987) and hairy vetch (Varco *et al.*, 1993). Initial N concentration of the different residues did not appear to be a factor in determining the relative change in N concentration of residue remaining with respect to placement regime. The lignin and lignin-N fractions of residues remaining were not reported in any of these studies. Greater N concentration of buried compared with surface-placed canola residue remaining corresponded to increased lignin-bound N, which would reduce potential N mineralization. Compositional changes in N fractions of decomposing residues, therefore do not necessarily relate to initial compositional effects on N mineralization potential. Crop residues with initially high N concentration would be predicted to have greater N mineralization potential than residues with initially low N concentration (Vigil and Kissel, 1991). However, N mineralization potential of residues remaining with increased N and lignin concentrations due to Maillard reactions during decomposition would be expected to be less than N mineralization potential of residues remaining with lower N and lignin concentrations. Further work is needed to clarify if initial N concentration, lignin content, specific environmental conditions (water content and temperature) during decomposition or other factors play a role and can be used to predict the potential for conservation of N during decomposition of crop residues in conservation tillage systems.

We conclude that canola residue decomposition was greater when buried than when surface-placed, despite having a greater fraction of total N as lignin-bound N in residue remaining throughout the decomposition period. More conducive water content for microbial activity on buried residue

Table 3. Regression equations fitted to data presented in figures

Property	Fig.	Placement	Intercept	Pool 1	Pool 2
Mass (g g⁻¹ original residue)	2a	Buried	0	$0.25\ e^{(-0.080\ DD)}$	$0.75\ e^{(-0.00057\ DD)}$
		Surface	0	$0.10\ e^{(-10\ DD)}$	$0.90\ e^{(-0.00026\ DD)}$
Acid-detergent fiber (g g⁻¹ original residue)	2b	Buried	0	$0.13\ e^{(-0.033\ DD)}$	$0.48\ e^{(-0.00054\ DD)}$
		Surface	0	$0.02\ e^{(-10\ DD)}$	$0.59\ e^{(-0.00026\ DD)}$
Lignin (mg g⁻¹ original residue)	2c	Buried	0	$122\ e^{(-0.00025\ DD)}$	NA
		Surface	0	$111\ e^{(-0.00016\ DD)}$	NA
Total N (mg g⁻¹ original residue)	2d	Buried-surface	0	$1.13\ e^{(-10\ DD)}$	$4.84\ e^{(-0.00043\ DD)}$
Cumulative C mineralization (mg g⁻¹ original residue 24 d⁻¹)	4a	Buried	0	$44\ e^{(-10\ DD)}$	$45\ e^{(-0.00002\ DD)}$
		Surface	0	$23\ e^{(-10\ DD)}$	$66\ e^{(-0.0005\ DD)}$
Rapidly-mineralizable C pool (mg g⁻¹ original residue)	4b	Buried	0	$86\ e^{(-0.052\ DD)}$	$11\ e^{(-0.0008\ DD)}$
		Surface	0	$17\ e^{(-10\ DD)}$	$80\ e^{(-0.0015\ DD)}$
Lignin N (mg g⁻¹ residue remaining)	5a	Buried	2.2	$0.002\ DD$	$1.0\ (1 - e^{(-0.031\ DD)})$
		Surface	2.3	$0.001\ DD$	NA
Lignin N (mg g⁻¹ lignin remaining)	5b	Buried-surface	19.4	$0.005\ DD$	NA
Total N (mg g⁻¹ residue remaining)	5c	Buried	5.85	$1.14\ (1 - e^{(-0.0051\ DD)})$	NA
			$0\quad 5.59\ e^{(-0.0002\ DD)}$		NA
Total N as Lignin N (g g⁻¹ residue remaining)	5d		$0.0003\ DD$		$0.13\ (1 - e^{(-0.038\ DD)})$
		0.36	$0.57\ (1 - e^{(-0.0008\ DD)})$		
		0.40			

NA is not applicable. DD is degree days (°C_>5 d).

appeared to be the primary factor for its greater rate of loss compared with surface-placed residue. The hypothesis that surface-placed residue undergoes compositional changes leading to more microbially resistant residue remained unsubstantiated. Surface placement of canola residue with low initial N concentration appears to spare residues from decomposition due to reduced contact with soil and more intensive drying–wetting rather than causing significant alterations in residue composition during decomposition.

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